FINAL REPORT

Advanced Wide Aperture Cluster for Surveillance (AWACS)

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Long Term Goals

The long term goal of this project was to operate Autonomous Underwater Vehicles in a complex oceanographic environment and determine environmental factors which affect transmission loss for low-frequency acoustic propagation in the shelfbreak front in the Middle Atlantic Bight.

Objectives

The objectives were to determine the impact of shelfbreak frontal variability and internal wave effects on transmission loss at the shelfbreak in the Middle Atlantic Bight.

Approach

We carried out three separate cruises with integrated physical oceanographic and shallow water acoustics measurements. These occurred during the Shallow Water 06/Non-Linear Internal Wave Initiative integrated experiment at the shelfbreak off New Jersey as well as during two additional cruises at the shelfbreak south of New England.

Tasks Completed

We successfully operated a REMUS 100 AUV during the SW06 Pilot Experiment in July, 2005. This was the first deployment of a REMUS vehicle in the shelfbreak front and was concurrent with mobile acoustic source runs along the proposed alongshelf mooring line for the main experiment. The mobile sources were operated by OASIS Inc. of Lexington, MA.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
This project involved making concurrent acoustic propagation & physical oceanographic measurements to determine environmental factors affecting low-frequency acoustic propagation in the shelfbreak front in the Middle Atlantic Bight. Autonomous Underwater Vehicles (AUVs) were used within the front to determine frontal structure as well as the impact of sound speed variability within the front on transmission loss. Successful AUV operations were conducted in three separate cruises. A list of environmental keys were determined which were simple means of determining the impact of shelfbreak frontal structure on acoustic propagation through adaptive sampling via mobile acoustic sources and sonobuoys.

15. SUBJECT TERMS
Acoustic propagation; Autonomous Underwater Vehicles (AUVs); Middle Atlantic Bight.

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We successfully did combined physical oceanography/shallow water acoustics operations during the SW06 experiment in August/September 2006. Rough weather precluded REMUS operations, but we performed high-resolution hydrographic surveys of the shelfbreak front with a towed Scanfish vehicle. A variety of mobile acoustic source runs were made, both alongshelf at the 80 m isobath and cross-shelf through the shelfbreak front. Runs were also made to test translational invariance and azimuthal isotropy by making two circular runs with the mobile sources with an alongshelf separation of 20 km.

During two cruises in May 2007 and 2008, we successfully operated multiple autonomous underwater vehicles within the shelfbreak front south of New England.

Results

The acoustics work under AWACS had two major components: 1) using the OASIS mobile acoustic sources (OMAS) to quantify ocean acoustic fluctuations and uncertainty as part of the Shallow Water 2006 (SW06) experiment and 2) using the REMUS vehicles with acoustic receivers to do source localization and tracking tasks.

The first task is being reported in the open literature, and will be discussed briefly here. The second task has some sensitivity to it, so we will not discuss it here; rather, we will briefly mention that sea trials were very successful in a series of detection, localization, and tracking tasks, and that this work has been further pursued in the PLUS-INP program.

Under the auspices of the SW06 experiment, a series of at-sea experiments were carried out to quantify the azimuthal dependence and translational invariance of acoustic transmission loss. An example of the source/receiver geometry used to study these issues is shown below in Figure 1.

The results of that study are have been assembled into a manuscript entitled "Are azimuthal isotropy and alongshelf translational invariance found in low-frequency acoustic propagation along the New Jersey shelfbreak? By P. Abbot, OASIS Inc., G. Gawarkiewicz, WHOI, J. Lynch, WHOI, J. Joseph, NPS, C. Emerson, OASIS Inc., A. Newhall, WHOI and I. Dyer, MIT. This manuscript will be submitted to the Journal of the Acoustical Society of America's special issue on the acoustics of the continental shelfbreak by September, 2010. Briefly, the results show that the TL can show fine angular scale (of order a few degrees) azimuthal dependence due to internal wave scattering, that it can show larger scale azimuthal variability due to larger scale oceanography (e.g. fronts), and that translational invariance over 10 km scales can come and go due to mesoscale and larger scale oceanographic variability. We have also published a number of other papers listed below relating to acoustic propagation in internal wave fields including their impact on geoacoustic inversions.

From the physical oceanographic perspective, we were able to examine the response of shelfbreak frontal structure to forcing by a large warm-core ring. A particularly dramatic result of the warm-core ring interaction was the formation of saline intrusions at the depth

of the seasonal pycnocline (Figure 2). These have been previously described by Lentz (2003) but have not been well-understood regarding either their forcing mechanism or their alongshelf scale. We found that the mis-match of the thermocline (and pycnocline) depths of the warm-core ring versus the continental shelf results in geostrophic adjustment in which intrusions are present within the observed 10-40 m depth range. Surprisingly, the alongshelf scale of the saline intrusion at the 80 m isobath, 20 km, was set by a large-amplitude frontal meander which propagated through the study area (Figure 3). We are currently completing a manuscript (Gawarkiewicz et al., 2010) on the structure of the shelfbreak front in the vicinity of the warm-core ring as well as the characteristics of the saline intrusion.

During the cruises in May 2007 and 2008, we successfully operated a number of autonomous underwater vehicles within the shelfbreak front. In 2007, we observed a small slope eddy offshore of the shelfbreak front. There was a near-surface layer of shelf water which overlaid the eddy and resulted in the offshore continuation of the cold pool duct from the continental shelf to the continental slope. We were able to successfully show that placing sources within this layer increased detection ranges substantially. In 2008, we observed an unusual event in which there was substantial offshore flow in the upper 20 m of the water column into a large amplitude Gulf Stream meander. As a result, the foot of the shelfbreak front was located substantially shoreward of its mean climatological position.

During the 2008 cruise, we successfully operated the REMUS in an autonomous environmental adaptive mode, in which the vehicle mapped the thermal boundary of the front. During summer of 2009, this method was improved and extended so that successful zig-zag mission were run within the Outer Cape Coastal Current east of Cape Cod. This was joint work with Dr. Samuel Smith of Pro Sapien Inc.

In addition, Gawarkiewicz also worked with a post-doctoral scholar, Andrey Shcherbina, to study cooling of a coastal current during winter (Shcherbina and Gawarkiewicz, 2007, 2008) as well as mapping of bathymetry at a coral reef (Shcherbina et al., 2008).

Impact for Science

During the course of this project, we were able to establish a number of environmental keys which affected the transmission loss. During the SW06 experiment, we were able to show that crossing the shelfbreak front lead to enhanced transmission loss. Detection ranges were maximized in transmission paths which were wholly onshore of the shelfbreak front. We defined the cross-shelf frontal position as the maximum cross-shelf temperature gradients at 40 m depth. In addition, we identified a persistent feature, the cold pool duct, which is the mid-depth temperature minimum of shelf water within the shelfbreak front. The underlying warm water is typically from the continental slope. A second environmental key was the vertical position of the temperature minimum within the water column. A third important environmental key was the cross-shelf position of the foot of the shelfbreak front. Finally, the depth of the surface mixed layer was also an important (and previously well-known) environmental key.

During the field experiments, we routinely operated multiple AUVs within a complex oceanographic environment with strong currents and large soundspeed variability (Figure 4). We worked out AUV deployment and recovery procedures for the R/V Hugh Sharp and R/V Tioga. We also worked out integrated sampling procedures involving detailed hydrographic operations during the night and AUV and mobile acoustic source operations during the day that allowed us to do sophisticated adaptive sampling and demonstrate the importance of the environmental keys mentioned above.

Relationship to Other Programs

This work preceded and influenced the Persistent Littoral Undersea Surveillance-Innovative Naval Prototypes program. Many of the integrated sampling techniques using the towed vehicles for high-resolution mapping and mobile acoustic source/sonobuoy sampling were used during the Quantifying, Predicting, and Exploiting Uncertainty DRI in the East China Sea.

Figures

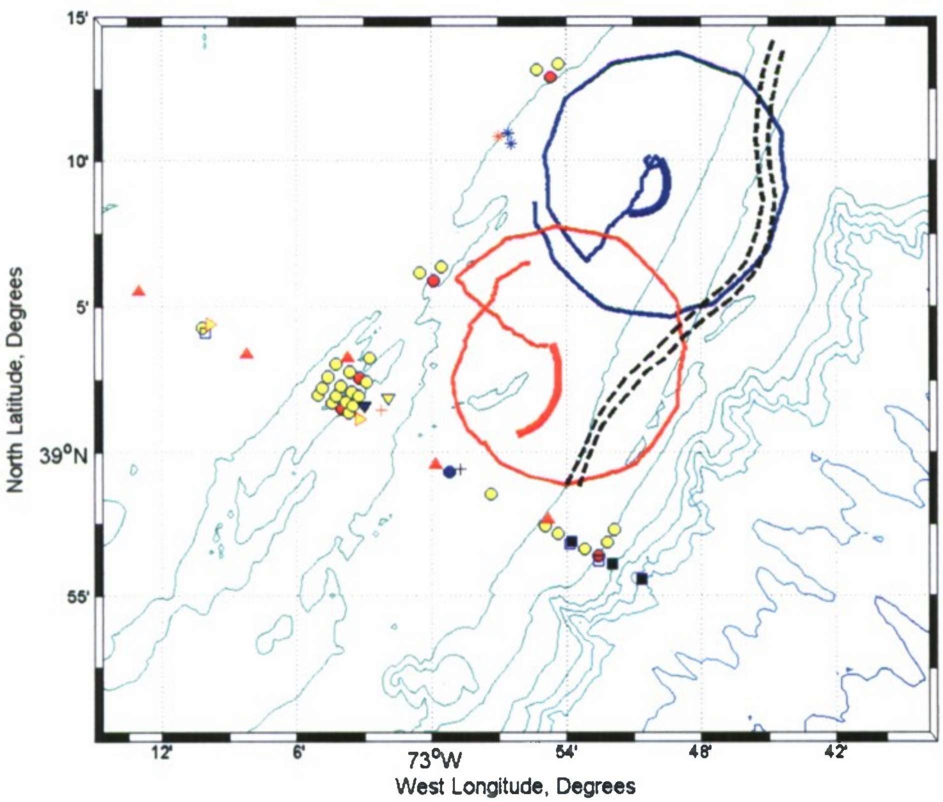

Figure 1. September 8, 2006 OMAS (OASIS Mobile Acoustic Source) and sonobuoy tracks used to study azimuthal dependence and translational invariance of transmission loss. The dotted lines mark the position of the shelfbreak front.

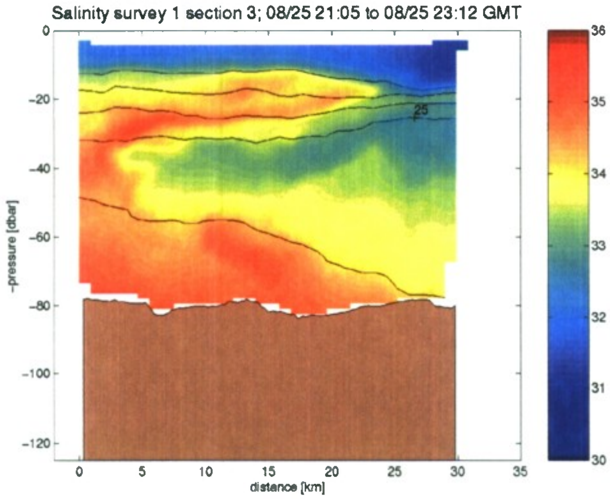

Figure 2- A section of salinity along the 80 m isobath from August 25, 2006 during the SW06 experiment showing the strong saline intrusion in the seasonal pycnocline. The thin black contour lines denote isopycnals.

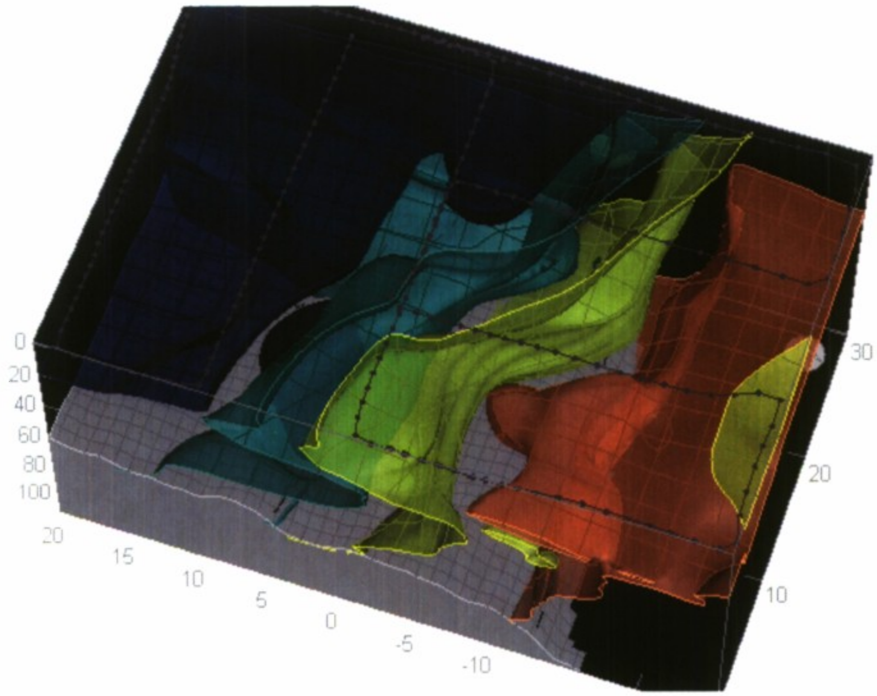

Figure 3- A visualization of the salinity field from August 26, 2006. The isosurfaces denote isohalines at 1 PSU increments with the orange surface representing a salinity of 35.5, yellow representing 34.5, and green representing 33.5. Note the 20 km offshore displacement of the yellow surface at the upper (northeastern) end of the domain relative to the lower (southwestern) end of the domain. The frontal meander propagated to the southwest at a speed of roughly 10 cm/s. Figure provided by A. Shcherbina.

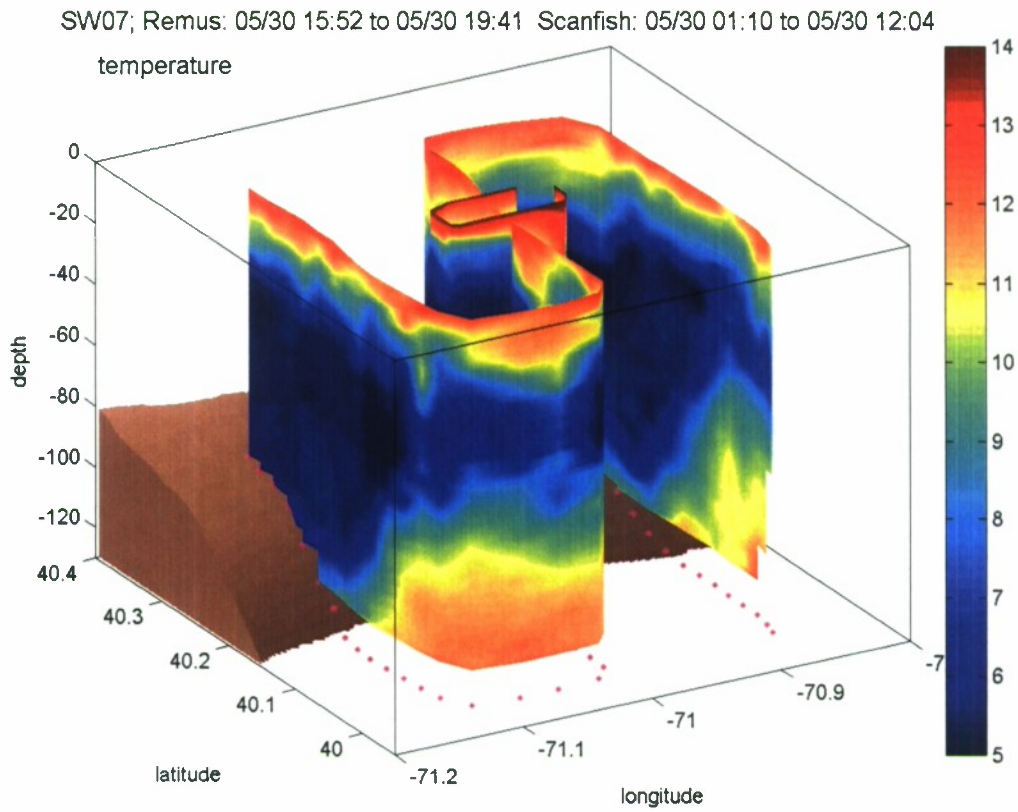

Figure 4- A visualization of the temperature field from May 30, 2007, obtained from both towed Scanfish (3 large cross-shelf sections) and one REMUS mission (small rectangular section in the middle of the domain). The Scanfish was operated during the night while the REMUS mission was occupied during concurrent acoustic measurements with a mobile acoustic source and sonobuoys. Figure provided by F. Bahr.

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